TECHNICAL REPORT

AMRA TR 63-08

LOW TEMPERATURE MECHANICAL PROPERTIES OF BASE AND WELD DEPOSITS OF SELECTED AUSTENITIC STAINLESS STEELS

by

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METALS AND CERAMICS RESEARCH LABORATORIES

U. S. ARMY MATERIALS RESEARCH AGENCY

JULY 1963

WATERTOWN 72, MASS.

The findings in this report are not to be construed as an official Department of the Army position.

Stainless steels

Steels, tensile properties

Steels, Charpy impact properties

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AMS Code 5026.11.842
Materials for Army Weapons and Combat Mobility

D/A Project 1-H-0-24401-A-110

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ABSTRACT

Mechanical properties of types 301, 310, 316, and 347 stainless steels in plate form were studied from room temperature down to -269 C. Both the base metal and weld deposits were tested. Charpy, true stress-strain, and notched tensile properties were examined.

The effect of testing temperature upon the tensile strength, elongation, reduction of area, true stress at maximum load, true stress at fracture, uniform strain, fracture strain, and notched strength ratio is illustrated. Companion data for Charpy impact energy are also included. The 310 and 316 alloys are shown to be insensitive to notches at low temperature, whereas the 301 and 347 alloys are notch sensitive.

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INTRODUCTION

The increased use of liquefied gases in missile propulsion systems has created a demand for engineering materials with good mechanical properties at cryogenic temperatures. As a result of this demand, considerable data have been published recently[1-4] on the cold-rolled austenitic stainless steels in sheet form, due mainly to the efforts of the missile industry.

However, the demand has not been met for impact and tensile properties at cryogenic temperatures of austenitic steels in bar and plate form and, especially, in the welded condition. With a few exceptions,[5,6] published data does not include true stress-strain data below -196 C nor does it include impact data at temperatures as low as -263 C.

The purpose of this report is to present engineering, true stress-strain tensile properties, and impact properties of base metal and welded specimens of AISI types 301, 310, 316, and 347 stainless steels.

MATERIALS AND PROCEDURE

Materials and Chemical Analysis

The materials used in this investigation together with the plate nomenclature and chemical analysis are shown in Table I.

TABLE I

MATERIALS AND CHEMICAL COMPOSITIONS

Material	Plate Thickness (inches)	Element (wt. %)									Average Grain Diameter (mm)
		C	Mn	Si	S	P	Ni	Cr	Mo	Cb	
301	13/16	.075	1.14	.49	.018	.028	7.04	18.83	----	---	.034
310	5/8	.070	1.80	.41	.003	.029	19.70	24.43	----	---	.126
316	5/8	.088	1.81	.45	.012	.026	12.84	16.64	2.29	---	.13
347	5/8	.068	1.46	.56	.019	.013	11.09	18.10	----	.88	.013

Welding Procedure

Plates 13/16 or 5/8-inch thick of the appropriate size to facilitate the machining of 3 inch-long tensile specimens and standard 2-1/16-inch-long Charpy notch impact specimens were machined and butt welded together. The weld joint contained an included angle of 45 degrees. All welds were manually deposited with matching composition covered electrodes, with the

exception of type 301 which was welded with type 308 electrode. Type 347 was root bead welded with 3/32-inch-diameter electrode and finished welded with 5/32-inch-diameter electrode; all other types were root bead welded with 1/8-inch-diameter electrode and finished welded with 5/32-inch-diameter electrode.

The welded and as-received blanks of types 301, 316, and 347 were annealed one hour at 1093 C (2000 F) and water quenched. Type 310 was annealed one hour at 1149 C (2100 F) and water quenched.

Testing Procedure

Standard 0.252-inch-diameter tension specimens with a 1.0-inch gage length were used. The notched tension specimens were 0.357-inch diameter and notched 50 percent to a 0.252-inch root diameter. The notch angle was 60 degrees and the root radius 0.002 inch for a $K_t = 6.3$.

Tensile tests were conducted in a Baldwin 60,000-pound hydraulic testing machine at a controlled platen speed of 0.01 inch per minute. Low temperature tension tests at -105 C and -196 C were conducted in a double-walled metal container. The coolants used were isopentane and liquid nitrogen at -105 C and liquid nitrogen at its boiling point, -196 C. Over this temperature range, a diameter gage[7] was used to obtain diameter data for true stress-strain calculations. For tests at -269 C, liquid helium was used in a tension cryostat.[8]

Impact tests at temperatures from room to -196 C were conducted in a 217 ft-lb Mouton impact machine. Impact tests at -263 C were conducted in an automatic impact cryostat.[8]

TEST RESULTS

The data obtained in this investigation are plotted in Figures 1 to 13 and tabulated in Tables II and III.

Engineering Properties

The base metal tensile strengths of the stainless steels investigated increased with decreasing temperature. Type 301 had the highest strength at all temperatures, and type 310 the lowest. The amount of increase in strength from room temperatures to -269 C increased with the strength level from 110,000 psi for type 310 to 154,000 psi for type 301 steel. It is noted on comparing the tensile strengths plotted in Figure 1 with the results for the welded specimens plotted in Figure 2 that the strength of types 310, 316, and 347 were almost identical for both the base metal and welded specimens. It is also noted that type 301 (which was welded with type 308 weld metal) had considerably lower strength than the base metal over the full temperature range, reflecting the lower strength of the type 308 composition.

TABLE II

BASE METAL TENSILE PROPERTIES

Testing Temp. (deg C)	Ultimate Tensile Strength (ksi)	Notch Tensile Strength (ksi)	Notched/ Unnotched Tensile Ratio	Elong. (%)	Reduction of Area (%)	True Stress at Max. Load (ksi)	Fracture Stress (ksi)	True Strain at Max. Load	Fracture Strain
AISI Type 301									
+24	138.0	98.0	0.69	53.0	68.0	202.5	328.0	.374	1.133
-105	214.0	187.5	0.88	33.0	61.0	280.0	380.0	.191	0.934
-196	270.5	144.5	0.53	32.0	53.0	328.0	443.5	.191	0.752
-269	294.0	134.0	0.45	28.0	47.0	400.0	552.5	.348	0.628
AISI Type 310									
+24	82.5	109.0	1.33	80.0	78.5	116.5	245.5	.348	1.577
-105	115.0	147.0	1.28	79.0	75.5	204.5	336.5	.575	1.402
-196	159.0	198.0	1.24	80.0	69.5	288.5	415.5	.523	1.178
-269	189.0	240.0	1.27	83.0	55.0	332.5	397.0	.565	0.799
AISI Type 316									
+24	84.0	101.5	1.21	78.0	73.5	134.5	238.5	.472	1.324
-105	126.5	148.5	1.17	81.0	74.5	207.5	362.0	.493	1.370
-196	178.5	203.0	1.14	64.0	68.0	278.5	430.0	.442	1.133
-269	212.0	226.0	1.06	54.0	55.0	337.5	469.0	.462	0.799
AISI Type 347									
+24	92.0	105.0	1.14	60.0	70.5	139.5	236.5	.413	1.218
-105	145.5	161.5	1.11	53.0	65.0	208.0	309.0	.346	1.051
-196	195.5	174.0	0.89	48.0	59.0	277.0	374.0	.346	0.884
-269	232.0	198.0	0.85	41.0	49.0	324.0	443.0	.346	0.873

TABLE III

WELD METAL TENSILE PROPERTIES

Testing Temp. (deg C)	Ultimate Tensile Strength (ksi)	Notch Tensile Strength (ksi)	Notched/ Unnotched Tensile Ratio	Elong. (%)	Reduction of Area (%)	True Stress at Max. Load (ksi)	Fracture Stress (ksi)	True Strain at Max. Load	Fracture Strain
AISI Type 301									
+24	88.7	94.0	1.12	34.0	58.0	148.0	202.0	.531	0.859
-105	157.0	124.5	0.8	25.0	41.0	216.0	251.5	.318	0.513
-196	188.0	136.5	0.73	18.0	21.0	236.0	238.5	.227	0.236
-269	184.0	163.0	0.88	15.0	19.5	228.0	228.0	.219	0.222
AISI Type 310									
+24	81.8	109.5	1.34	62.0	78.0	119.0	218.0	.374	1.518
-105	117.5	144.5	1.23	68.0	75.0	189.0	314.5	.472	1.388
-196	158.8	189.0	1.19	61.0	52.0	282.5	326.5	.575	0.729
-269	184.4	238.0	0.99	50.0	47.0	350.0	371.5	.640	0.640
AISI Type 316									
+24	80.2	101.5	1.26	55.0	60.0	129.0	183.0	.472	0.909
-105	124.0	126.0	1.01	60.0	51.5	194.0	242.0	.442	0.718
-196	170.5	163.5	0.96	53.0	54.0	266.0	352.0	.442	0.776
-269	200.5	196.0	0.98	50.0	43.0	346.5	355.5	.535	0.554
AISI Type 347									
+24	92.0	110.5	1.20	59.0	68.5	134.0	215.0	.374	1.147
-105	150.0	130.5	0.87	62.0	66.5	227.0	290.0	.413	1.092
-196	197.0	151.5	0.77	48.0	60.5	271.0	360.0	.318	0.821
-269	227.0	174.0	0.77	41.0	30.0	336.0	432.5	.390	0.890

The reduction of area of the base metal generally decreased with decreasing temperature. The behavior of the elongation was less consistent, often showing a maximum at some intermediate temperature. The elongation of type 310 increased from 63 percent at room temperature to 80 percent at -196 C and then decreased to 63 percent at -269 C. Type 316 reached a maximum at -105 C.

The elongation and reduction of area values of the welded types 301 (which was welded with type 308 weld metal) and 316 were generally lower than the base metal properties. The ductility of the welded type 347 specimens compared favorably with the base metal properties.

The notched tensile strength of the base and welded specimens shown in Figures 3 and 4 generally increased with decreasing temperature. The exception was the notch strength of type 301 base metal which decreased below -105 C. The notch strength of the type 301 (which was welded with type 308 weld metal), while lower than the base metal strength, increased with decreasing temperature to -269 C. The notched:unnotched tensile ratios, also plotted in Figures 3 and 4, generally decreased with decreasing temperature. Types 310 and 316 had excellent toughness at -269 C in both the base and welded condition, while type 347 had only moderate toughness below -105 C. The toughness of type 301, however, was poor below -105 C.

True Stress-Strain Properties

Linear plots of true stress-strain for the temperature range investigated are shown in Figures 5 to 8. The curves at -269 C were plotted from data obtained from serrated load-elongation curves[8] and instantaneous diameter measurements obtained with the tension cryostat. True stress data were obtained by dividing the area of the specimen at the start of the serration into the peak load of the serration. These data, therefore, reflect the upper envelope of the flow stress curve.

In general, the flow stress increased with decreasing temperature. An exception was noted in the low strain region of the curves for types 301 and 347. These steels both showed a region at low strains where the stress-strain curves are concave upward. In this region, the flow stress at -269 C was lower than the flow stress at -196 C. This behavior and the shape of the stress-strain curve can be attributed to the stress-induced transformation of austenite to martensite during the test.

The flow stress of the type 301 (type 308 weld metal) was considerably lower than the type 301 base metal over the full temperature range. It was observed, also, that the concave upward trend was not evident at room temperature. In the welded type 301 specimens the deformation occurred mainly in the type 308 weld metal.

The true stress at maximum load σ_m and at fracture σ_f indicated in Figures 5 to 8 by the filled and open symbols, respectively, and plotted

in Figures 9 and 10, generally increased with decreasing temperature. The exceptions were true stress at both maximum load and at fracture for the type 301 (type 308 welded metal) and true stress at fracture for type 310.

True strain at fracture, ϵ_f, shown in Figure 11, decreased with decreasing temperature. True strain at maximum load, ϵ_m, however, did not follow this trend. The strain, ϵ_m, of type 310 increased with decreasing temperature to -105 C and remained relatively constant to -269 C. For types 316 and 347, ϵ_m was relatively constant over the whole temperature range. However, strain at maximum load for type 301 decreased from 0.36 at room temperature to 0.19 at -196 C and then increased to 0.34 at -269 C.

The fracture strain of the welded specimens, Figure 12, decreased sharply with decreasing temperature. Strain at maximum load of type 301 (type 308 welded metal), also plotted in Figure 12, decreased with decreasing temperature. The strains at maximum load of the remaining weld metals were higher at -269 than at -196 C. The increased strain at maximum load below -196 C was characteristic of the serrated stress-strain curves encountered in this region. Here the deformation process was not continuous at any one location, but rather, several necks formed before maximum load, and the deformation shifted from location to location at each serration.[8]

Impact Properties

The base and weld metal impact properties are shown in Figure 13. The energy required to fracture the annealed base metal specimen of types 301, 310, and 347 exceeded the capacity of the 217 ft-lb impact tester from room temperature to -140 C. Below -140 C, type 301 exhibited a sharp transition and fractured at 155 C after absorbing 106 ft-lb and at -263 C with 82 ft-lb. Type 347 fractured at -196 C with an absorbed energy of 208 ft-lb and decreased to 161 ft-lb at -263 C. Type 310, however, did not fracture at -196 C nor at -263 C. The impact energy of annealed type 316 reached a maximum of 155 ft-lb at -40 C and decreased to 97 ft-lb at -263 C. The transition in type 301 was caused by transformation of austenite to martensite in this heat on cooling to temperatures below -140 C.

The impact properties of the welded specimens decreased with decreasing temperature, with no sharp transition. Type 310, with an impact energy of 120 ft-lb at room temperature, had an absorbed energy of 50 ft-lb at -263 C. The remaining alloys were closely grouped between 26 and 30 ft-lb at -263 C.

SUMMARY

The mechanical properties of AISI types 301, 310, 316, and 347 stainless steel plate, in both the annealed base metal and welded and annealed conditions, were determined at temperatures from room to -269 C. Charpy impact and notched tensile properties were also determined. Type 301 showed the highest strength at all temperatures and type 310 the lowest in the base metal. The tensile strengths of types 310, 316, and 347 were almost identical for both the base metal and welded specimens. Type 301 (type 308 weld metal) had considerably lower strength over the full temperature range, showing the lower strength of the type 308 composition.

The toughness of types 310 and 316 at -269 C, as measured by notched-unnotched tensile ratios, was excellent in both the base and welded condition, while type 347 had only moderate toughness below -105 C and type 301 had poor toughness below -105 C.

Type 301 base metal underwent a sharp transition in the Charpy impact test below -140 C. Type 310 base metal had the best impact properties, and exceeded the capacity of the impact cryostat pendulum at -263 C.

The impact properties of the welded specimens were lower than those of the base metal, and decreased with decreasing temperature, but did not show a sharp transition.

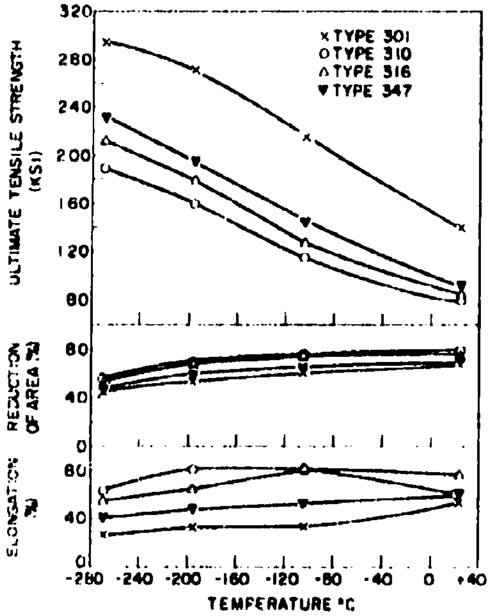

Figure 1. 300 Series Stainless Steels

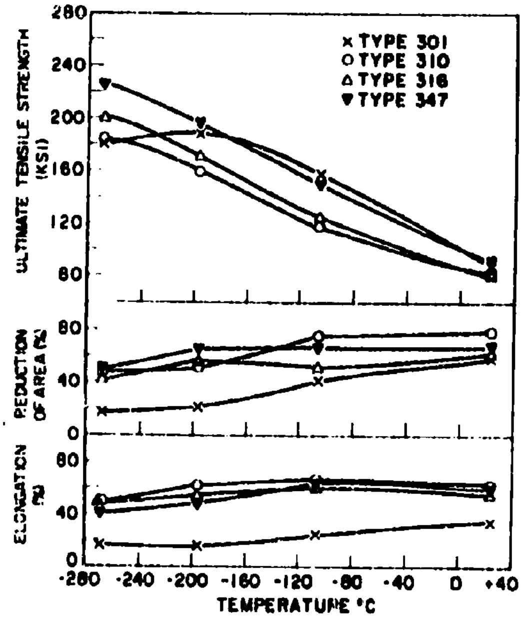

Figure 2. Welded 300 Series Stainless Steels

ENGINEERING TENSILE PROPERTIES VERSUS TESTING TEMPERATURE

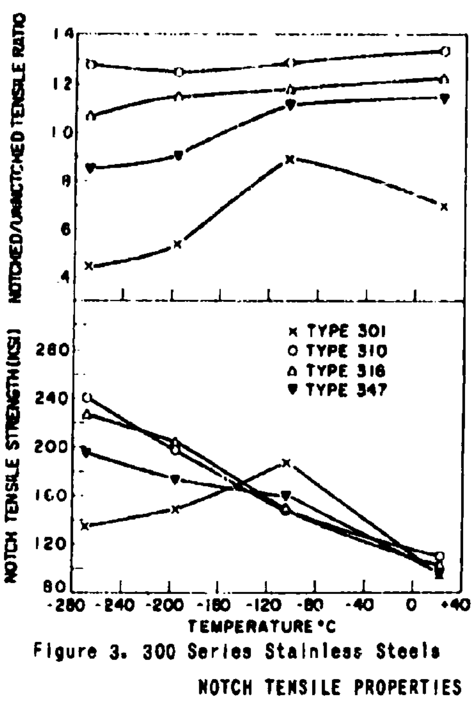

Figure 3. 300 Series Stainless Steels

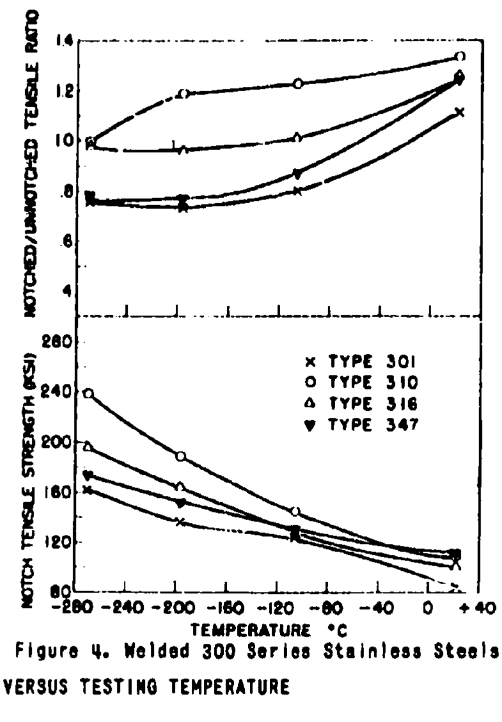

Figure 4. Welded 300 Series Stainless Steels

NOTCH TENSILE PROPERTIES VERSUS TESTING TEMPERATURE

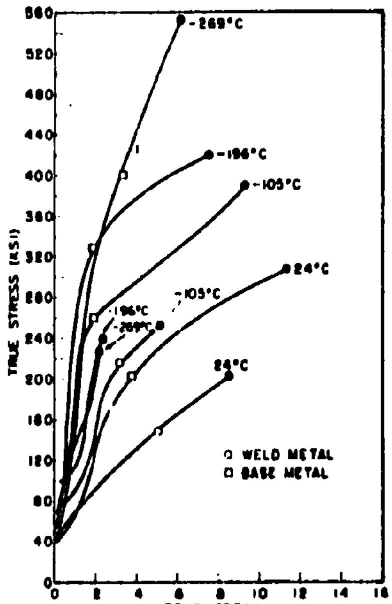

Figure 5. AISI 301

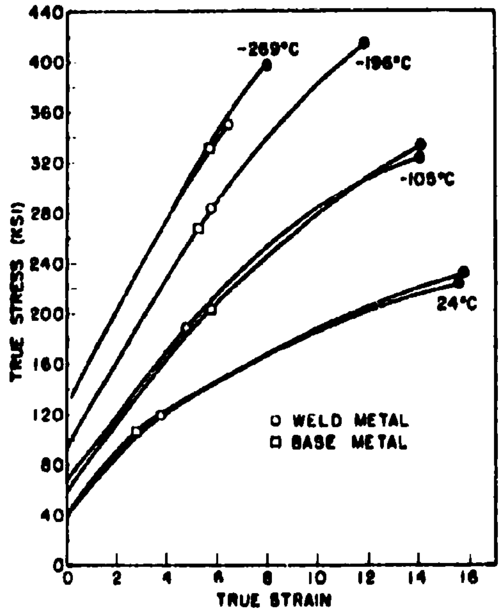

Figure 6. AISI 310

TRUE STRESS-STRAIN CURVES OF BASE AND WELDED STAINLESS STEELS AT VARIOUS TEMPERATURES

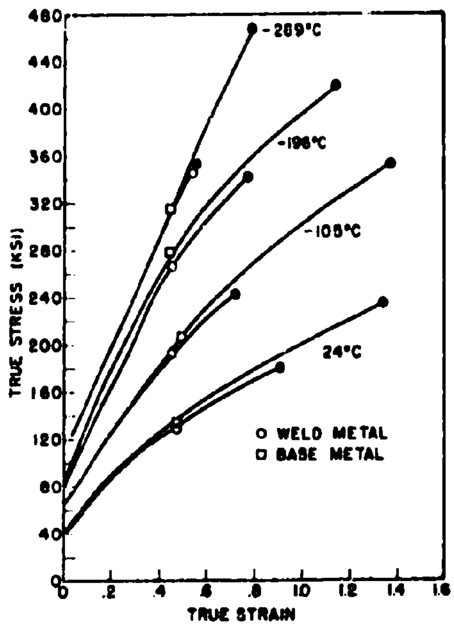

Figure 7. AISI 316

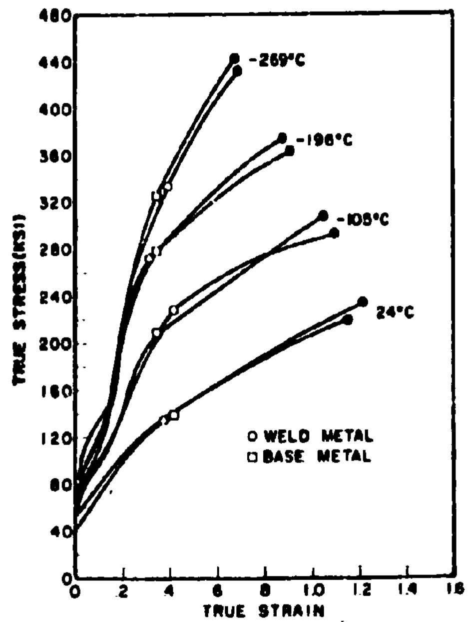

Figure 8. AISI 347

TRUE STRESS-STRAIN CURVES OF BASE AND WELDED STAINLESS STEELS AT VARIOUS TEMPERATURES

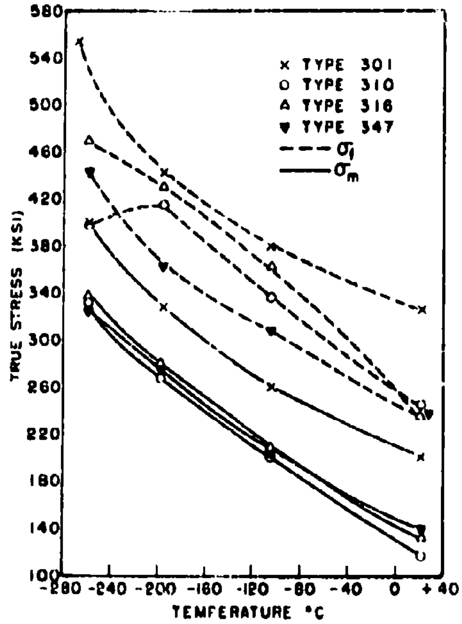

Figure 9. 300 Series Stainless Steels

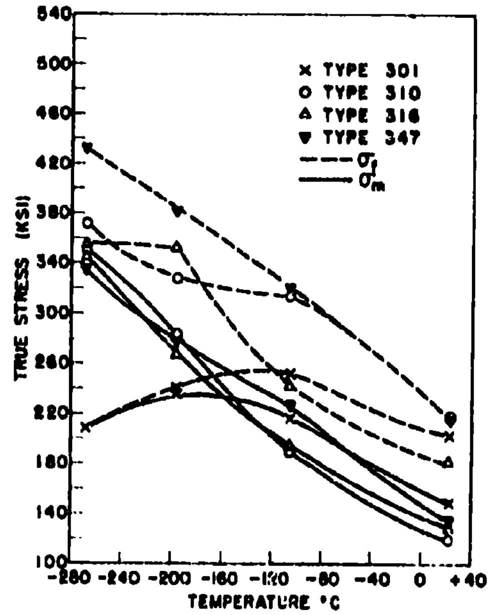

Figure 10. Welded 300 Series Stainless Steels

EFFECT OF TEMPERATURE ON TRUE STRESS AT FRACTURE AND MAXIMUM LOAD

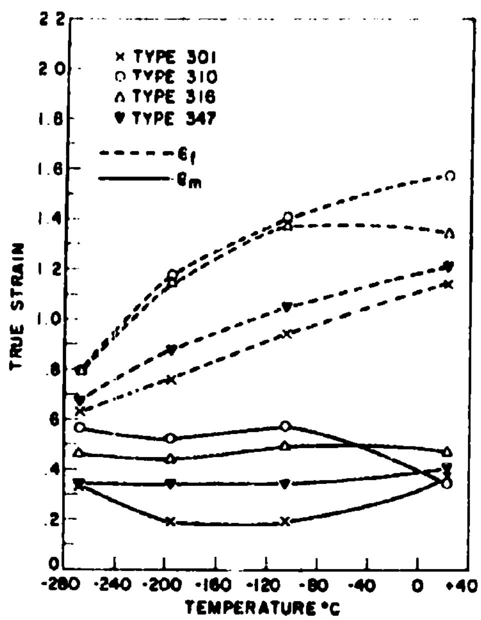

Figure 11. 300 Series Stainless Steels

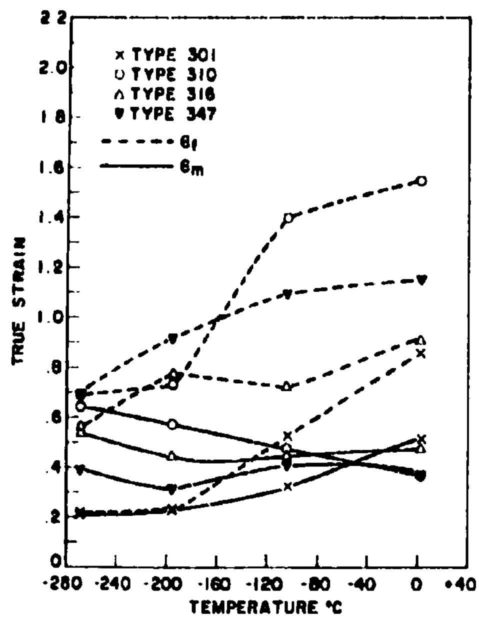

Figure 12. Welded 300 Series Stainless Steels

EFFECT OF TEMPERATURE ON TRUE STRAIN AT FRACTURE AND MAXIMUM LOAD

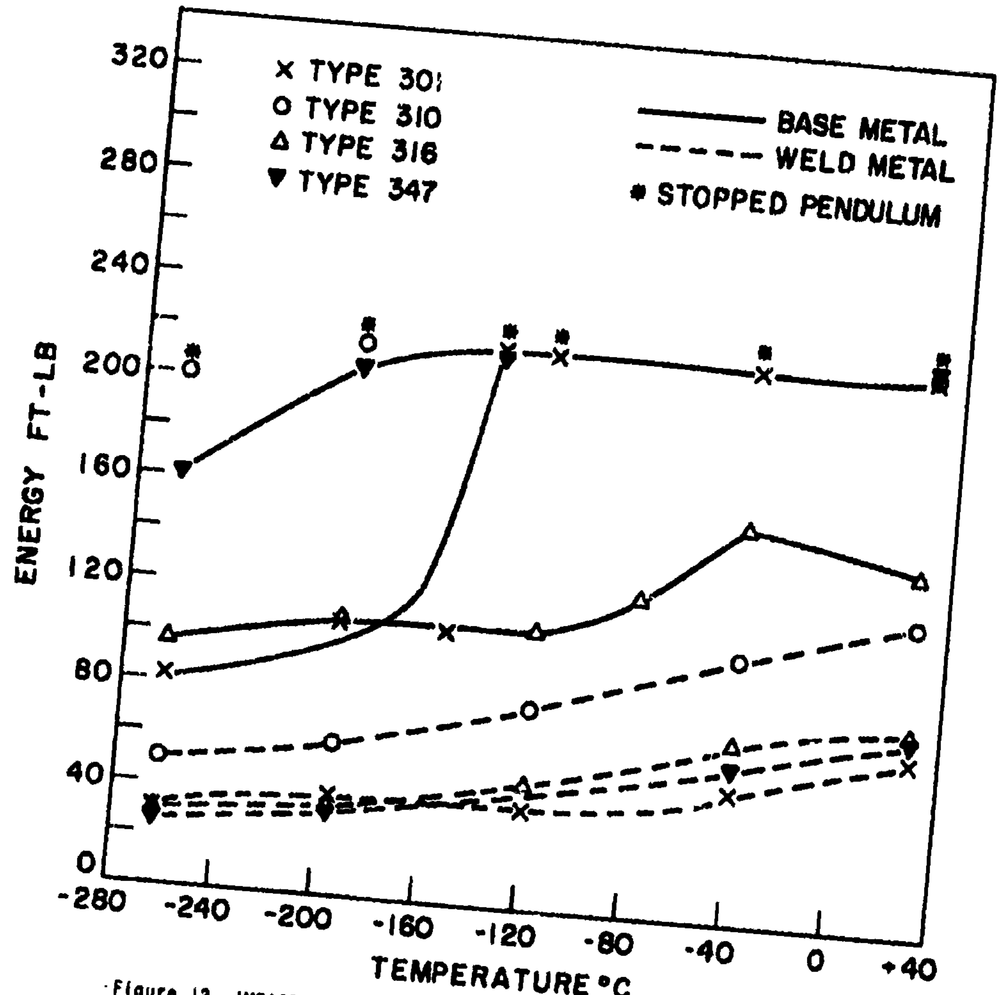

Figure 13. IMPACT ENERGY VERSUS TESTING TEMPERATURE OF BASE AND WELDED 300 SERIES STAINLESS STEELS

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The effect of testing temperature upon the tensile strength, elongation, reduction of area, true stress at maximum load, true stress at fracture, uniform strain, fracture strain, and notched strength ratio is illustrated. Companion data for Charpy impact energy are also included. The 310 and 316 alloys are shown to be insensitive to notches at low temperature, whereas the 301 and 347 alloys are notch sensitive.

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